PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improvements in and relating to Electric Control Systems

We, THE ENGLISH ELECTRIC COMPANY LIMITED, of Queens House, 28 Kingsway, London, W.C.2, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electric control systems.

According to the present invention, an electric control system for controlling a physical quantity or characteristic of a continuous moving material in accordance with an adjustable reference signal comprises, in combination, reference means for producing the adjustable reference signal, regulating means for varying the physical quantity or characteristic of the material, detecting means spaced from the regulating means in the direction of motion of the material for producing a signal varying in dependence upon the physical quantity or characteristic of the material passing the detecting means, comparison means responsive to the reference signal and to the signal produced by the detecting means for producing an output dependent upon the difference of the two signals, actuating means responsive to the output of the comparison means for adjusting the regulating means in a sense tending to reduce the output of the comparison means, and interrupter means for rendering the actuating means intermittently ineffective to adjust the regulating means, the actuating means being effective to adjust the regulating means during spaced periods of time occurring at a predetermined frequency, and the comparison means having an input circuit time constant approximately equal to the time taken for any given part of the material to move from the regulating means to the detecting means.

The input circuit time constant of the comparison means may in cases where the speed of the continuous moving material is relatively low become large, for example, of the order of five seconds, as compared with control system time constants normally encountered.

The continuous moving material may comprise, for example, a continuous material such as a strip material leaving the rolls of a rolling mill, or a continuously-flowing comminuted material such as crushed iron ore carried on a conveyor.

According to another feature of the invention, where the speed of the material may be adjusted at will, the interrupter means may be arranged to vary automatically the frequency at which the said spaced periods of time occur substantially in dependence upon the speed of the material.

According to another feature of the invention, the interrupter means is arranged so that the spaced periods of time are of substantially constant duration for all speeds of the continuous moving material.

According to a further feature of the invention, the adjustable reference signal and the output signal of the detecting means may be voltages, and the comparison means in such a case may comprise a resistor and a capacitor connected in series to form a series circuit of relatively large time constant across which the difference of the said voltages is applied, and an amplifying means arranged to produce an output voltage varying in accordance with the voltage developed across the capacitor.

According to yet another feature of the invention, the amplifying means may comprise a magnetic amplifying means, and the interrupter means may be arranged to control the alternating current supply circuit to the magnetic amplifying means whereby to render the actuating means effective or ineffective to adjust the regulating means.

Two electric control systems according to

the present invention will now be described by way of example with reference to the accompanying drawing and to the drawing accompanying the Provisional Specification. The first control system is arranged to control the time rate of mass flow of a crushed material such as iron ore from a storage receptacle to a delivery point, whilst the second control system is arranged to control the thickness of a strip material issuing from the rolls of a strip rolling mill. Figures 1 and 2 of the accompanying drawing show block schematic diagrams of the two control systems respectively, whilst the Figure shown in the drawing accompanying the Provisional Specification shows a detailed schematic diagram of one example of a mass flow control system having a block schematic diagram as shown in Fig. 1.

Referring now to Fig. 1, a variable-speed 'delivery' belt conveyor 10 having a driving drum 10*a* and an idler drum 10*b* is arranged to receive a substantially uniform flow of crushed iron ore 11 from a supply hopper 12 mounted above one end of the conveyor, the volume of material deposited on each foot of the conveyor being maintained substantially constant by manually-adjustable preset regulator means (not shown) associated with the hopper.

The delivery conveyor 10 is driven in the direction shown by the arrow, and is arranged to deliver the crushed material to a constant-speed 'weighing' belt conveyor 13 having a driving drum 13*a* and an idler drum 13*b*. The driving drums 10*a* and 13*a* of the respective conveyors are driven by two D.C. electric motors 14 and 15 respectively, the latter running at constant speed and the former being controlled by a quick-acting speed-sensitive closed-loop control system 100 in accordance with the setting of a speed reference device 101. The speed feedback link is shown at 100*a*.

The speed reference device is arranged for adjustment by an actuator 102 which controls it in accordance with the output signal of a comparison device 103, this output signal being dependent on the deviation of a 'mass flow' reference signal provided by a manually-adjustable 'mass flow' reference device 104.

The 'mass flow' signal is derived from a 'mass flow' responsive device 105 which is arranged to measure by means of a weight-responsive deflection system the weight of crushed iron ore passing on the belt conveyor over a given area. Since the belt travels at constant speed the output signal of the 'mass flow' responsive device is representative of the true rate of 'mass flow' of the crushed iron ore.

It will be appreciated from the above that the system so far described would tend to operate in a manner such as to vary the speed of the driving motor 14, and hence the speed of the variable-speed delivery belt conveyor 10, in a manner tending to reduce the deviation of the 'mass flow' signal from the value corresponding to the 'mass flow' reference signal. However, due to the physical separation of the regulating means (that is, the supply hopper and the variable-speed conveyor) and the detecting or sensing means (that is, the mass flow responsive device) relatively large time intervals are present between the determination and detection of the controlled quantity (mass flow). These inevitably result in poor accuracy of control, and perhaps in the instability of the control system.

To overcome this time lag effect the input circuit of the comparison device is arranged to have a relatively large time constant—of the same order of magnitude as the time taken by the crushed material to reach the 'mass flow' responsive device 105 after leaving the supply hopper—and the automatic adjustment of the speed reference device 101 by the actuator 102 is rendered intermittent, instead of continuous, by an interrupter 106 which is arranged to be driven by the variable-speed driving motor 14. The interrupter is arranged in operation to render the actuator intermittently responsive to the output of the comparison device 103. Since the interrupter is driven in accordance with the speed of the delivery conveyor 10 the frequency of the periods of time during which the actuator is responsive to the output of the comparison device varies directly in accordance with the speed of the delivery conveyor. The interrupter is so arranged that the successive periods of energisation of the actuator remain of constant duration for all operating speeds of the delivery conveyor 10.

Thus correction of the speed reference device 101 by the actuator 102 is made at successive intervals of time corresponding to the passage of equal lengths of the delivery belt conveyor—and hence of the crushed material on the conveyor—past any given point. By this means the initiation of the re-adjustment of the speed reference device 101 is directly related to the distance travelled by the delivery conveyor and the material carried thereby, and not to time.

Due to the intermittent nature of this automatic adjustment of the speed reference device 101 by the actuator 102, the control system tends to follow the trend of any gradual change in the 'mass flow' rate and to correct therefor, but does not respond to temporary fluctuations in the 'mass flow' rate.

A more detailed description of such a control system for controlling the time rate of 'mass flow' of comminuted material will be given later with reference to the drawing accompanying the Provisional Specification, where parts already shown in Fig. 1 bear the same reference as in Fig. 1.

Referring now to Fig. 2, strip material 200 issuing from between the rolls 201, 202 of a strip rolling mill is gauged for thickness by a

'gauge' micrometer 203 disposed at a position beyond the rolls in the direction of motion of the strip material. The output signal of the 'gauge' micrometer is compared in a comparison device 204 with a 'gauge' reference signal supplied by a manually-adjustable 'gauge' reference device 205. The output of the comparison device is supplied to an actuator 206, which is arranged to vary the setting of an adjustable 'screw-down' position reference device 207 for a quick-acting position-sensitive closed-loop control system 208 which is itself arranged to control the position of the screw-down motors 209 of the rolling mill whereby to control the gauge of the strip material leaving the rolling mill. The position feedback link is shown at 208*a*.

As in the case of the 'mass flow' control system the input circuit of the comparison device 204 is arranged to have a time constant of the order of the time taken for the strip material to reach the 'gauge' micrometer 203 after leaving the rolls of the mill, and an interrupter 210 driven by the rolling mill is arranged to render the actuator 206 intermittently, instead of continuously, responsive to the output of the comparison device 204. Since the interrupter is driven by the rolling mill, the frequency of the periods of time during which the actuator is responsive to the output of the comparison device varies directly in accordance with the speed of the strip material as it leaves the rolls. The interrupter is also arranged so that the successive periods of energisation of the actuator remain of constant duration for all operating strip material speeds of the rolling mill.

Thus, as in the 'mass flow' control system, correction or re-adjustment of the screw-down position reference device 207 is made at successive intervals of time corresponding to the passage of equal lengths of strip material past any given point. The initiation of the re-adjustment of the position reference device is thus directly related to the distance travelled by the strip material, and not to time. The control system, therefore, tends to follow the trend of any gradual change in the strip material 'gauge' and to correct therefor, but does not respond to temporary fluctuations in the 'gauge.'

Referring now to the more detailed circuit diagram shown in the drawing accompanying the Provisional Specification the two D.C. electric motors 14 and 15 for driving the driving drums 10*a* and 13*a* of the variable-speed and constant-speed conveyors 10 and 13 respectively have armatures 14*a* and 15*a* which are connected in parallel with one another across the armature 16*a* of a variable-voltage generator 16 arranged to be driven at constant speed by a motor not shown.

The generator output voltage is controlled by varying the current flowing in a field winding 16*b* of the generator from a potentiometer 17 connected across D.C. supply busbars 18.

The weighing conveyor motor 15 has a field winding 15*b* which is arranged to be excited by a constant current so that for the given generator output voltage the motor runs at substantially constant speed.

The delivery conveyor motor 14 has a main field winding 14*b* supplied from the D.C. supply busbars 18, the field current flowing therethrough being varied by means of a field regulator 19, and an auxiliary field winding 14*c* supplied by a single-ended type magnetic amplifier 20 which is arranged to produce an output varying in accordance with an input signal determined by the excess of a speed reference voltage over an e.m.f. generated by a D.C. tacho-generator 21 coupled to the driving motor 14 and delivery conveyor 10. The auxiliary field winding 14*c* is arranged to oppose the main field winding 14*b* so that the magnetic amplifier 20 is effective to reduce the field excitation of the driving motor 14, thus increasing its speed, as the input signal of the magnetic amplifier increases. Hence the magnetic amplifier 20 tends to maintain the speed of the driving motor 14 in accordance with the magnitude of the speed reference voltage.

The speed reference voltage comprises the voltage difference between the sliding contacts 22*a* and 23*a* of two independent parallel-connected potentiometers 22 and 23, one of the potentiometers, 22, being a generator voltage compensating potentiometer and the other, 23, a speed reference potentiometer.

The tacho-generator 21 has a field winding 21*a* which is connected in series with the two parallel-connected potentiometers 22 and 23 across the D.C. supply busbars 18, variation of the tacho-generator field excitation being obtained by means of an adjustable diverter 24 connected in parallel with the field winding 21*a*.

The weighing conveyor 13 has a displaceable weighing table 25 mounted below and in contact with the upper belt of the conveyor, being pressed against the upper belt by a biasing spring 26 acting through a pivoted beam 27. The weighing table is arranged for displacement from a predetermined unloaded position in accordance with the weight of material on the upper belt, the table being effective when displaced to rotate the pivoted beam about its pivot 27*a* against the action of the biasing spring. The displacement of the table is magnified by the pivoted beam which has coupled thereto, at the end opposite the biasing spring, the moving member 28*a* of a linear differential transformer 28.

The input winding 28*b* of the linear differential transformer is supplied through an isolating transformer 29 from an A.C. supply source 30, and the output winding 28*c* is connected through a full-wave bridge rectifier network 31 to a load resistor 32. The displace-

ment of the weighing table 25 under load from its unloaded position is effective to move the movable member 28*a* of the linear differential transformer in one direction from its central position thus increasing the D.C. output voltage developed across the load resistor 32 in accordance with the displacement of the weighing table.

A mass flow reference voltage is obtained from a mass flow reference potentiometer 33 which is arranged to be supplied through a generator voltage compensating potentiometer 34 from a further full-wave bridge rectifier network 35 connected to the A.C. supply source 30.

The positive end 32*a* of the load resistor 32 is connected to the positive end 33*a* of the mass flow reference potentiometer 33, and a series circuit comprising a capacitor 36 and a resistor 37 is connected between the negative end 32*b* of the load resistor and the sliding contact 33*b* of the mass flow reference potentiometer.

A voltage dependent on the difference of the mass flow reference voltage and the voltage developed across the load resistor 32 is thus applied to the series circuit, and since the values of capacitance and resistance of the capacitor and resistor respectively are chosen so that the time constant of the series circuit is of the order of 5 seconds the voltage developed across the capacitor is substantially independent of small rapid variations in the voltage applied to the series circuit caused by small isolated variations in the uniformity of the loading of the delivery conveyor 10.

The input terminals of a push-pull type magnetic amplifier 38 are connected across the capacitor 36, the output terminals of the amplifier being connected to the armature 39*a* of a constantly-excited D.C. pilot motor 39 arranged to drive the sliding contact 23*a* of the speed reference potentiometer 23.

The push-pull magnetic amplifier is arranged to be supplied intermittently from the A.C. supply source 30 through the normally-open contacts 40*a* of a slugged relay 40. The slugged relay is arranged to be energised intermittently from the D.C. supply busbars 18 through contacts 41*a* operated by a a cam-follower 41*b* which is arranged to be actuated by a cam-wheel 41*c* driven through gearing 42 from the driving motor 14 of the delivery conveyor 10. The contacts 40*a* are arranged to close on energisation of the slugged relay and to remain closed for a predetermined constant time interval of the order of 1 second.

The push-pull magnetic amplifier 38 is arranged to produce a D.C. voltage varying in both magnitude and sense in accordance with the magnitude and sense of the voltage developed across the capacitor 36, the sense of the output being such as to increase the speed reference voltage for the driving motor 14 when the voltage developed across the load resistor 32 is less than the mass flow reference voltage, i.e. when the time rate of mass flow over the weighing table is less than the desired amount as determined by the setting of the mass flow reference potentiometer 33, and vice versa.

Correction of the setting of the speed reference potentiometer 23 by the pilot motor 39 occurs only when the contacts 40*a* of the slugged relay are closed, so that the speed reference voltage is adjusted intermittently only. Furthermore since the contacts of the slugged relay close each time the cam-wheel 41*c* strikes the cam-follower 41*b* and since the cam-wheel is driven by the delivery conveyor driving motor 14, correction is initiated at successive intervals corresponding to the passage of equal lengths of the delivery conveyor past any given point. Hence the frequency at which correction occurs varies directly with the speed of the delivery conveyor. By this means the initiation of the correction of the speed reference voltage is directly related to the distance travelled by the delivery conveyor and not to time.

An increase in the mass flow rate for a given speed of the weighing conveyor 13 requires a reduction in the total field excitation of the delivery conveyor driving motor 14 whereby to increase the speed of the delivery conveyor 10. In order that the auxiliary field winding 14*c* of the delivery conveyor driving motor shall exert only a small controlling influence on the driving motor for all settings of the mass flow reference potentiometer 33 the sliding contact 33*a* of this potentiometer is ganged with the field regulator 19 controlling the field excitation current in the main field winding 14*b* of the driving motor 14, so that the field excitation due to this main field winding is reduced by an amount corresponding substantially to the desired change in the mass flow rate when the mass flow reference voltage is increased. Furthermore, in order to compensate for the influence on the tacho-generator 21 of this change in the current in the main field winding 14*b* the sliding contact 33*a* of the mass flow reference potentiometer 33 is ganged with the field diverter 24 of the tacho-generator so as to reduce the excitation of the tacho-generator as the mass flow reference voltage is increased, thus causing the closed-loop speed control system (incorporating the single-ended magnetic amplifier 20) to settle at a higher speed for a given setting of the speed reference potentiometer 23.

The sliding contact 17*a* of the generator field potentiometer 17 is ganged with those of the generator voltage compensating potentiometers 22 and 34 so that if the generator voltage is increased the mass flow reference voltage is reduced to compensate for the increased speed of the weighing conveyor 13

consequent on an increase in the generator voltage, and so that the speed reference voltage is increased so as to cause the delivery conveyor driving motor 14 to settle at a correspondingly higher speed for a given setting of the speed reference potentiometer 23.

In operation, if due to a change in the characteristics, e.g. the specific gravity of the material delivered from the hopper on to the delivery conveyor the mass flow rate begins to fall, the weight of material influencing the weighing table 25 decreases thus causing the displacement of the weighing table to be reduced, and consequently the D.C. output voltage developed across the load resistor 32 falls. This results in an increase in the voltage applied to the input side of the push-pull magnetic amplifier 38 so that eventually on closure of the contacts 40*a* of the slugged relay 40 the armature of the pilot motor 39 is energised by an increased current sufficient to cause it to drive the sliding contact 23*a* of the speed reference potentiometer 23 in a direction such as to increase the speed reference voltage. The single-ended magnetic amplifier 20 responds to the increase in its input signal by increasing the current flowing in the driving motor auxiliary field winding 14*c* thus decreasing the field excitation of the driving motor 14 and thereby increasing its speed. The mass flow rate is thus increased towards the value determined by the setting of the mass flow reference potentiometer 33. Correction of the speed reference voltage continues throughout successive periods of energization of the magnetic amplifier 38 until the voltage applied to the pilot motor armature 39*a* is insufficient to cause it to rotate further.

If, for any reason, the mass flow rate increases above the value determined by the setting of the mass flow reference potentiometer 33, the voltage across the load resistor 32 rises above the mass flow reference voltage thus reversing the input to the push-pull amplifier 38. As a result the pilot motor 39 is energised on closure of the slugged relay contacts 40*a* in a sense tending to reduce the speed reference voltage, thus reducing, when the voltage applied to the pilot motor armature 39*a* is sufficiently large, the field current in the auxiliary field winding 14*c* of the driving motor 14 and thereby increasing the field excitation of the driving motor. The motor speed thus falls so as to reduce the rate of mass flow towards the value determined by the setting of the mass flow reference potentiometer 33. Correction of the speed reference voltage may continue throughout successive periods of energisation of the magnetic amplifier 38 until the voltage applied to the pilot armature 39*a* is insufficient to rotate it.

Due to the intermittent nature of the control of the speed reference potentiometer 23 by the pilot motor 39 the system tends to follow the trend of any change in the mass flow rate and therefore does not respond to temporary fluctuations in the mass flow rate.

Whereas in the system just described the speed of the delivery conveyor driving motor 14 is controlled by varying the field excitation, the armature voltage remaining constant, in an alternative system the field excitation is maintained constant and the magnetic amplifier 20 is arranged to control the generator output voltage whereby to control the speed of the driving motor. In such a system the driving motor 15 would be supplied by a separate generator.

The apparatus shown in the lower right-hand part of the figure is similar to that used in one 'gauge' control system arranged according to the Fig. 2, the lever 27 being arranged to be deflected by a roller member running in contact with and arranged to be deflected by the surface of the strip material. The gauge micrometer 203 of Fig. 2 comprises said roller member, the lever 27 and associated biasing spring 26, the differential transformer 28, the full-wave bridge rectifier 31 and the load resistor 32, the output signal of the 'gauge' micrometer being developed across the resistor 32. The 'gauge' reference device 205 comprises the potentiometer 33, whilst the comparison device 204 comprises the R—C circuit 36, 37 in conjunction with the push-pull amplifier 38. The actuator 206 comprises the pilot motor 39, and the potentiometer 23 constitutes the screw-down position reference device 207 for the screw-down motor position-sensitive closed-loop control system. The gearing 42 through which the cam 41*c* is driven is arranged to be coupled with the rolling mill so that the contacts 41*a* are closed repeatedly at a frequency dependent on the speed of the strip material leaving the rolling mill.

WHAT WE CLAIM IS:—

1. An electric control system for controlling a physical quantity or characteristic of a continuous moving material in accordance with an adjustable reference signal comprising, in combination, reference means for producing the adjustable reference signal, regulating means for varying the physical quantity or characteristic of the material, detecting means spaced from the regulating means in the direction of motion of the material for producing a signal varying in dependence upon the physical quantity or characteristic of the material passing the detecting means, comparison means responsive to the reference signal and to the signal produced by the detecting means for producing an output dependent upon the difference of the two signals, actuating means responsive to the output of the comparison means for adjusting the regulating means in a sense tending to reduce the output of the comparison means, and interrupter means for rendering the actuating means intermittently ineffective to adjust the regulating means, the

actuating means being effective to adjust the regulating means during spaced periods of time occurring at a predetermined frequency, and the comparison means having an input circuit time constant approximately equal to the time taken for any given part of the material to move from the regulating means to the detecting means.

2. An electric control system according to Claim 1, wherein the speed of the material is adjustable at will, and wherein the interrupter means is arranged to vary automatically the frequency at which the said spaced periods of time occur in dependence upon the speed of the material.

3. An electric control system according to Claim 2, wherein the interrupter means is arranged so that the spaced periods of time are of substantially constant duration for all speeds of the material.

4. An electric control system according to any preceding Claim, wherein the adjustable reference signal and the output signal of the detecting means are voltages, and wherein the comparison means comprises a resistor and a capacitor connected in series to form a series circuit of relatively large time constant across which the difference of the said voltages is applied, and an amplifying means arranged to produce an output voltage varying in accordance with the voltage developed across the capacitor.

5. An electric control system according to Claim 4 as appended to Claim 2 or 3, wherein the amplifying means comprises a magnetic amplifying means, and wherein the interrupter means is arranged to control the alternating current supply circuit to the magnetic amplifying means whereby to render the actuating means effective or ineffective to adjust the regulating means.

6. An electric control system according to any preceding Claim for controlling the time rate of mass flow of a comminuted material from a receptacle in accordance with the reference signal, wherein the regulating means comprises, in combination, a variable-speed conveyor on to which the comminuted material is discharged from the receptacle, adjustable regulator means for controlling the flow of material so that the conveyor carries away from the receptacle a layer of substantially constant volume per unit length of conveyor, variable-speed driving means for driving the variable-speed conveyor, and speed regulating means for varying the speed of the variable-speed driving means; wherein the detecting means comprises, in combination, a constant-speed conveyor on to which the variable-speed conveyor is arranged to discharge the comminuted material, constant-speed driving means for driving the constant-speed conveyor, and weighing means responsive to the weight of material for the time being passing over a predetermined section of the constant-speed conveyor for producing an output signal varying in accordance therewith; and wherein the comparison means is responsive to the adjustable reference signal and to the output signal of the weighing means, and the actuating means is arranged to adjust the speed regulating means in a manner tending to reduce the deviation of the weighing means output signal from a value corresponding to the adjustable reference signal.

7. An electric control system according to Claim 6, wherein the actuating means comprises an electric motor for adjusting the speed regulating means in a corrective sense in dependence upon the output of the comparison means.

8. An electric control system according to Claim 6 or Claim 7, wherein the interrupter means is arranged to be driven directly or indirectly by the variable-speed conveyor so as to vary the frequency of the spaced periods of time in accordance with the speed of the variable-speed conveyor.

9. An electric control system according to Claim 8, wherein the interrupter means comprises switch means arranged for operation by a cam driven directly or indirectly by the variable-speed conveyor so as to control a relay having contact means for controlling the energisation of the actuating means, the relay being arranged so that on energisation the contact means remain closed, and the actuating means energised, for a predetermined time interval.

10. An electric control system according to any of Claims 6 to 9, wherein the speed regulating means comprises a speed-sensitive closed-loop control system for maintaining the speed of the variable-speed driving means substantially in accordance with the setting of an adjustable speed reference means, the actuating means being arranged to adjust the setting of the speed reference means.

11. An electric control system according to any of Claims 1 to 5, arranged to control the thickness of a strip material leaving the rolls of a rolling mill in accordance with the reference signal, wherein the regulating means comprises, in combination, screw-down means for varying the separation of the rolls of the mill, screw-down position regulating means for regulating the position of the screw-down means so as to regulate the thickness of the strip material leaving the rolls; wherein the detecting means comprises gauge means for producing an output signal varying in accordance with the thickness of the strip material passing through the gauge means; and wherein the comparison means is responsive to the adjustable reference signal and to the output signal of the gauge means, the actuating means being arranged to adjust the screw-down position regulating means so as to vary the separation of the rolls of the mill in a manner tending to reduce the deviation of the gauge means

output signal from a value corresponding to the adjustable reference signal.

12. An electric control system according to Claim 11, wherein the actuating means comprises an electric motor for adjusting the screw-down position regulating means in a corrective sense in dependence upon the output of the comparison means.

13. An electric control system according to Claim 11 or Claim 12, wherein the interrupter means is arranged to be driven directly or indirectly by the rolling mill so as to vary the frequency of the spaced periods of time in accordance with the speed of the rolling mill.

14. An electric control system according to Claim 13, wherein the interrupter means comprises switch means arranged for operation by a cam driven directly or indirectly by the rolling mill so as to control a relay having contact means for controlling the energisation of the actuating means, the relay being arranged so that on energisation the contact means remain closed, and the actuating means energised, for a predetermined time interval.

15. An electric control system according to any of Claims 11 to 14, wherein the screw-down position regulating means comprises a position-sensitive closed-loop control system for maintaining the position of the screw-down means substantially in accordance with the setting of an adjustable screw-down position reference means, the actuating means being arranged to adjust the setting of the screw-down position reference means.

16. An electric control system substantially as herein described with reference to Figure 1 of the accompanying drawing.

17. An electric control system substantially as herein described with reference to Figure 2 of the accompanying drawing.

18. An electric control system substantially as herein described with reference to the drawing accompanying the Provisional Specification.

F. A. WEBSTER,
Agent for the Applicants.

PROVISIONAL SPECIFICATION

Improvements in and relating to Electric Control Systems

We, THE ENGLISH ELECTRIC COMPANY LIMITED, of Queens House, 28, Kingsway, London, W.C.2, a British Company, do hereby declare this invention to be described in the following statement:—

This invention relates to apparatus for controlling the mass flow of a comminuted material.

According to one feature of the invention apparatus for controlling the time rate of mass flow of a comminuted material at a predetermined value includes, in combination, a variable-speed delivery conveyor having means for delivering the comminuted material substantially uniformly on to the conveyor, a constant-speed weighing conveyor on to which the delivery conveyor is arranged to deliver material, weighing means arranged to weigh the material passing on the weighing conveyor over a predetermined area or position and arranged to produce an output quantity varying in accordance with the weight of material for the time being influencing the weighing means, and control means arranged to compare the output quantity of the weighing means with a predetermined reference quantity and to vary the setting of a speed regulating means controlling the delivery conveyor in a corrective sense in accordance with the difference of the two quantities whereby to maintain the time rate of mass flow of material from the delivery conveyor to the weighing conveyor substantially in accordance with the magnitude of the reference quantity.

According to another feature of the invention the control means is arranged to vary the setting of the speed regulating means intermittently during periods which occur at a frequency whhich varies in accordance with the speed of the delivery conveyor.

Preferably the periods during which the setting of the speed regulating means is varied are of a predetermined constant duration.

The control means may comprise an electric control means, and the output quantity of the weighing means and the reference quantity may comprise electric quantities.

Other features of the invention will appear from the following description, with reference to the accompanying drawing, of one apparatus according to the invention arranged to control the time rate of mass flow of crushed iron ore.

Referring now to the drawing a variable-speed delivery belt conveyor 10 having a driving drum 10*a* and an idler drum 10*b* is arranged to receive a substantially uniform flow of a comminuted material 11 from a supply hopper 12 mounted above the conveyor, the volume of material deposited on each foot of the conveyor being substantially constant.

The delivery conveyor is driven in the direction shown by the arrow and is arranged to deliver the material to a constant-speed weighing belt conveyor 13 having a driving drum 13*a* and an idler drum 13*b*. The driving drums 10*a* and 13*a* of the two conveyors are driven respectively by two D.C. electric motors 14 and 15 whose armatures 14*a* and 15*a* are connected in parallel across the armature 16*a* of a variable-voltage generator 16

driven at constant speed by a motor not shown. The generator output voltage is controlled by varying the current flowing in a field winding 16*b* of the generator from a potentiometer 17 connected across D.C. supply busbars 18.

The motor 15 driving the weighing conveyor 13 has a field winding 15*b* which is arranged to be excited by a constant current so that for the given generator output voltage the motor runs at substantially constant speed.

The motor 14 driving the delivery conveyor 10 has a main field winding 14*b* supplied from the D.C. supply busbars 18, the field current flowing therethrough being varied by means of a field regulator 19, and an auxiliary field winding 14*c* supplied by a single-ended type magnetic amplifier 20 which is arranged to produce an output varying in accordance with an input signal determined by the excess of a speed reference voltage over an e.m.f. generated by a D.C. tacho-generator 21 coupled to the driving motor 14 and delivery conveyor 10. The auxiliary field winding 14*c* is arranged to oppose the main field winding 14*b* so that the magnetic amplifier 20 is effective to reduce the field excitation of the driving motor 14, thus increasing its speed, as the input signal of the magnetic amplifier increases. Hence the magnetic amplifier 20 tends to maintain the speed of the driving motor 14 in accordance with the magnitude of the speed reference voltage.

The speed reference voltage comprises the voltage difference between the sliding contacts 22*a* and 23*a* of two independent parallel-connected potentiometers 22 and 23, one of the potentiometers, 22, being a generator voltage compensating potentiometer and the other, 23, a speed reference potentiometer.

The tacho-generator 21 has a field winding 21*a* which is connected in series with the two parallel-connected potentiometers 22 and 23 across the D.C. supply busbars 18, variation of the tacho-generator field excitation being obtained by means of an adjustable diverter 24 connected in parallel with the field winding 21*a*.

The weighing conveyor 13 has a displaceable weighing table 25 mounted below and in contact with the upper belt of the conveyor, being pressed against the upper belt by a biasing spring 26 acting through a pivoted beam 27. The weighing table is arranged for displacement from a predetermined unloaded position in accordance with the weight of material on the upper belt, the table being effective when displaced to rotate the pivoted beam about its pivot 27*a* against the action of the biasing spring. The displacement of the table is magnified by the pivoted beam which has coupled thereto at the end opposite the biasing spring the moving member 28*a* of a linear differential transformer 28.

The input winding 28*b* of the linear differential transformer is supplied through an isolating transformer 29 from an A.C. supply source 30, and the output winding 28*c* is connected through a full-wave bridge rectifier network 31 to a load resistor 32. The displacement of the weighing table 25 under load from its unloaded position is effective to move the movable member 28*a* of the linear differential transformer in one direction from its central position thus increasing the D.C. output voltage developed across the load resistor 32 in accordance with the displacement of the weighing table.

A mass flow reference voltage is obtained from a mass flow reference potentiometer 33 which is arranged to be supplied through a generator voltage compensating potentiometer 34 from a further full-wave bridge rectifier network 35 connected to the A.C. supply source 30.

The positive end 32*a* of the load resistor 32 is connected to the positive end 33*a* of the mass flow reference potentiometer 33, and a series circuit comprising a capacitor 36 and a resistor 37 is connected between the negative end 32*b* of the load resistor and the sliding contact 33*b* of the mass flow reference potentiometer.

A voltage dependent on the difference of the mass flow reference voltage and the voltage developed across the load resistor 32 is thus applied to the series circuit, and since the values of capacitance and resistance of the capacitor and resistor respectively are chosen so that the time constant of the series circuit is of the order of 5 seconds the voltage developed across the capacitor is substantially independent of small rapid variations in the voltage applied to the series circuit caused by small isolated variations in the uniformity of the loading of the delivery conveyor 10.

The input terminals of a push-pull type magnetic amplifier 38 are connected across the capacitor 36, the output terminals of the amplifier being connected to the armature 39*a* of a constantly-excited D.C. pilot motor 39 arranged to drive the sliding contact 23*a* of the speed reference potentiometer 23.

The push-pull magnetic amplifier is arranged to be supplied intermittently from the A.C. supply source 30 through the normally-open contacts 40*a* of a slugged relay 40. The slugged relay is arranged to be energised intermittently from the D.C. supply busbars 18 through contacts 41*a* operated by a cam-follower 41*b* which is arranged to be actuated by a cam-wheel 41*c* driven through gearing 42 from the driving motor 14 of the delivery conveyor 10. The contacts 40*a* are arranged to close on energization of the slugged relay and remain closed for a predetermined constant time interval of the order of 1 second.

The push-pull magnetic amplifier 38 is arranged to produce a D.C. voltage varying in both magnitude and sense in accordance

with the magnitude and sense of the voltage developed across the capacitor 36, the sense of the output being such as to increase the speed reference voltage for the driving motor 14 when the voltage developed across the load resistor 32 is less than the mass flow reference voltage, i.e. when the time rate of mass flow over the weighing table is less than the desired amount as determined by the setting of the mass flow reference potentiometer 33, and vice versa.

Correction of the setting of the speed reference potentiometer 23 by the pilot motor 39 occurs only when the contacts 40*a* of the slugged relay are closed, so that the speed reference voltage is adjusted intermittently only. Furthermore since the contacts of the slugged relay close each time the cam-wheel 41*c* strikes the cam-follower 41*b* and since the cam-wheel is driven by the delivery conveyor driving motor 14, correction is initiated at successive intervals corresponding to the passage of equal lengths of the delivery belt conveyor past any given point. Hence the frequency at which correction occurs varies directly with the speed of the delivery conveyor. By this means the initiation of the correction of the speed reference voltage is directly related to the distance travelled by the delivery belt conveyor and not to time.

An increase in the mass flow rate for a given speed of the weighing conveyor 13 requires a reduction in the total field excitation of the delivery conveyor driving motor 14 whereby to increase the speed of the delivery conveyor 10. In order that the auxiliary field winding 14*c* of the delivery conveyor driving motor shall exert only a small controlling influence on the driving motor for all settings of the mass flow reference potentiometer 33 the sliding contact 33*a* of this potentiometer is ganged with the field regulator 19 controlling the field excitation current in the main field winding 14*b* of the driving motor 14, so that the field excitation due to this main field winding is reduced by an amount corresponding substantially to the desired change in the mass flow rate when the mass flow reference voltage is increased. Furthermore, in order to compensate for the influence on the tacho-generator 21 of this change in the current in the main field winding 14*b* the sliding contact 33*a* of the mass flow reference potentiometer 33 is ganged with the field diverter 24 of the tacho-generator so as to reduce the excitation of the tacho-generator as the mass flow reference voltage is increased, thus causing the closed-loop speed control system (including the single-ended magnetic amplifier 20) to settle at a higher speed for a given setting of the speed reference potentiometer 23.

The sliding contact 17*a* of the generator field potentiometer 17 is ganged with those of the generator voltage compensating potentiometers 22 and 34 so that if the generator voltage is increased the mass flow reference voltage is reduced to compensate for the increased speed of the weighing conveyor 13 consequent on an increase in the generator voltage, and so that the speed reference voltage is increased so as to cause the delivery conveyor driving motor 14 to settle at a correspondingly higher speed for a given setting of the speed reference potentiometer 23.

In operation, if due to a change in the characteristics, e.g. the specific gravity, of the material delivered from the hopper on to the delivery conveyor the mass flow rate begins to fall, the weight of material influencing the weighing table 25 decreases thus causing the displacement of the weighing table to be reduced, and consequently the D.C. output voltage developed across the load resistor 32 falls. This results in an increase in the voltage applied to the input side of the push-pull magnetic amplifier 38 so that eventually on closure of the contacts 40*a* of the slugged relay 40 the armature of the pilot motor 39 is energized by an increased current sufficient to cause it to drive the sliding contact 23*a* of the speed reference potentiometer 23 in a direction such as to increase the speed reference voltage. The single-ended magnetic amplifier 20 responds to the increase in its input signal by increasing the current flowing in the driving motor auxiliary field winding 14*c* thus decreasing the field excitation of the driving motor 14 and thereby increasing its speed. The mass flow rate is thus increased towards the value determined by the setting of the mass flow reference potentiometer 33. Correction of the speed reference voltage continues throughout successive periods of energization of the magnetic amplifier 38 until the voltage applied to the pilot motor armature 39*a* is insufficient to cause it to rotate.

If, for any reason, the mass flow rate increases above the value determined by the setting of the mass flow reference potentiometer 33, the voltage across the load resistor 32 rises above the mass flow reference voltage thus reversing the input to the push-pull amplifier 38. As a result the pilot motor 39 is energized on closure of the slugged relay contacts 40*a* in a sense tending to reduce the speed reference voltage, thus reducing, when the voltage applied to the pilot motor armature 39*a* is sufficiently large, the field current in the auxiliary field winding 14*c* of the driving motor 14 and thereby increasing the field excitation of the driving motor. The motor speed thus falls so as to reduce the rate of mass flow towards the value determined by the setting of the mass flow reference potentiometer 33. Correction of the speed reference voltage may continue throughout successive periods of energization of the magnetic amplifier 38 until the voltage applied to the pilot motor armature 39*a* is insufficient to rotate it.

Due to the intermittent nature of the con-

trol of the speed reference potentiometer 23 by the pilot motor 39 the system tends to follow the trend of any change in the mass flow rate and therefore does not respond to temporary fluctuations in the mass flow rate.

Whereas in the system just described the speed of the delivery conveyor driving motor 14 is controlled by varying the field excitation, the armature voltage remaining constant, in an alternative system the field excitation is maintained constant and the magnetic amplifier 20 is arranged to control the generator output voltage whereby to control the speed of the driving motor.

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854,215 COMPLETE SPECIFICATION
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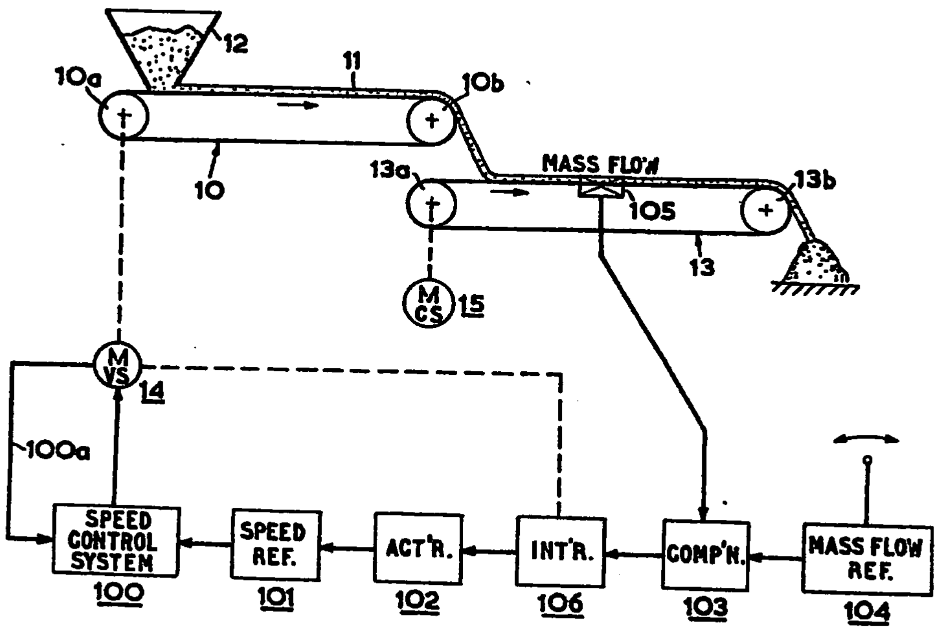

FIG.1

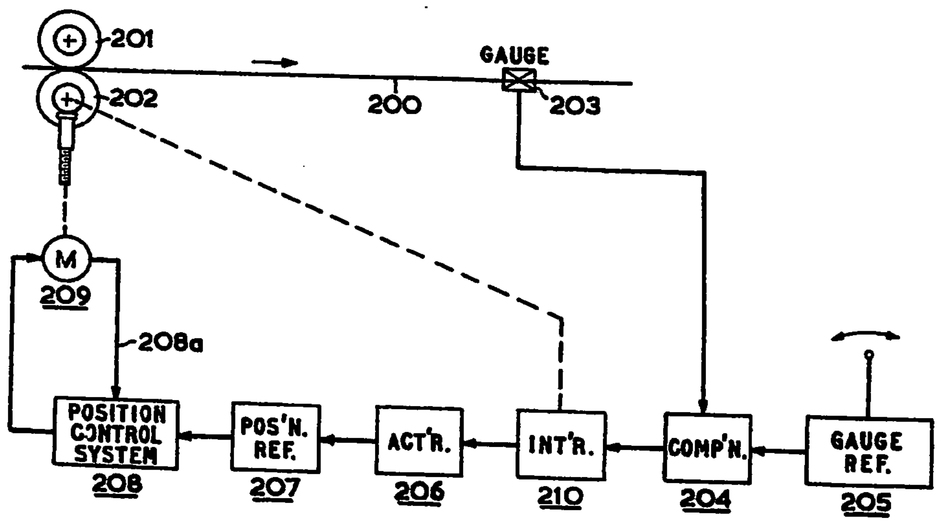

FIG.2

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PROVISIONAL SPECIFICATION

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